DOI:
10.1109/PIMRC.2016.7794901

Document Version
Peer reviewed version

Citation for published version (APA):
Gang, J., & Friderikos, V. (2016). Control plane load balancing in wireless C/U split architectures. In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC* (pp. 1-6). [7794901] Institute of Electrical and Electronics Engineers Inc.. https://doi.org/10.1109/PIMRC.2016.7794901

Control Plane Load Balancing in Wireless C/U Split Architectures

Jinwei Gang, Vasilis Friderikos
Centre of Telecommunications Research
King's College London, Strand, London, WC2R 2LS, UK

***Abstract*—The goal of expected 5G networks is to bring ultra high data rates to mobile users. To realize this, a novel Control and User plane split (C/U) communication network paradigm that deploys a large number of small base stations within the coverage area of a macro cell has been considered. However, an emerging problem for such architecture is the increasing complexity in control network load balancing and hand over events. Such problems for control plane has received little attention and it is the focus of this paper. We propose an optimal solution to the mentioned problems and discuss the related performance via numerical investigations.**

***Index Terms*—5G wireless network, phantom cells, C-plane/ U-plane Spit, HetNet, load balancing, user handover**

I. INTRODUCTION

Undoubtedly, cell densification in 5G wireless networks is expected to allow for ultra high achievable data rates. In order to efficiently realize high cell density networks, an architectural paradigm shift is taking place towards the physical and/or logical split of the Control and User planes (C/U planes). Since user plane performance is inevitably intertwined with that of the control plane, special attention should be paid for cases of congestion episodes, where limited control plane capacity might adversely affect overall network performance. In this paper we provide network optimization algorithms for C/U split architectures with emphasis on control plane load balancing and C-plane load reduction by taking into account inter macro controller handovers and back-hauling limitations. Numerical investigations reveal that proposed solutions can provide significant gains in terms of network performance compare to baseline techniques.

The control and user (i.e. data forwarding) plane separation (C/U split) is expected to provide a significant facilitation towards the co-existence of different radio technologies including high capacity small cells within the same network that are orchestrated by a common control infrastructure. Such re-thinking on the cellular architecture is required to accommodate future needs; it is now estimated that by 2020, mobile user demand for data will generate an order of thousand times the traffic level on mobile networks compared to year 2010. In a C/U split plane network domain macro cells act as the network control plane that efficiently manage real time resources of a large number of high capacity small cells (including future mmWave-based cells) that can serve mobile users always 'on demand'. To handle the increasing data demand from mobile users it comes as no surprise the move towards the use of very dense, low-power, small cell wireless networks that will unlock the potential of extremely high spatial reuse (especially when utilizing spectrum at the mmWave bands). Small cell networks allow for increased capacity by spatial localized transmissions (i.e. bring small access points closer to the user) whilst leveraging a more efficient spectrum utilization by allowing multiple concurrent connections to different access points for a mobile user [1]. The concept of C/U split has been envisioned in the setting of small 'phantom' cells [1] that will serve mobile users (U-plane) while being controlled by a macro base station operating at different frequency bands [2], [3] and [4].

Hand in hand with the aforementioned benefits arrive a set of challenges when moving towards the envisioned extreme cell densification scenarios [8]. Not least among those, and items of attention in this study, are issues related to macro base station and small cell association and coordinated management that will become an increasingly difficult and complex network function in the near future. To this end, we detail a set of optimization problem aiming to increase the performance of C/U split architectures under the assumption of a potentially large number of small cell and associated user mobility. More specifically, we are interested in dynamic policies for assigning small cells to macro base stations in the overlapped control area (controlled by multiple macros) by taking into account control plane load conditions aiming to avoid degradation on the performance due to congestion episodes. Besides that, seeking a way to reduce as much handover rates as possible is also our consideration since the load re-distribution would easily cause massive handover in a architecture with dense small cells. We furthermore assume a logical decoupling between the control and user plane domain via software defined networking (SDN). In an essence, SDN enabled wireless access and core networks provide a hardware agnostic programmable framework for easing the development of new network functionalities and isolating complexities through the separation of control and data plane [10]. SDN will allow the required flexibility in network monitoring, policy installation and network management and hence act as a catalyst in allowing novel network orchestration techniques to be adopted in the C/U plane split wireless architectures as envisioned in this paper.

In addition to that, advanced algorithm like our proposal will be able to run via network cloudification [9], fully

[1]In this paper the terms pico cells, small cells and phantom cells are used interchangeably.

programmable RAN [11] as well as network sharing [12]. Load balancing has been mainly considered in macro cell mobile networks via various versions of the cell breathing technique [13] where BSs (base stations) adjust their coverage area by changing their transmission power depending on load conditions. Recently some efforts have also been detailed in load balancing in HetNet environments[14][15] but to the best of our knowledge there is no work for load balancing and handover reduction in C/U split architectures. The rest of the paper is organized as follows. In section II we detail background work on C/U split wireless architectures with focus on issues related to the problems investigated in this paper. In section III we detail the problems that we are trying to attack and provide a set of mathematical programming formulations as pertain to the issues of load balancing and handover rates reduction in C/U split architectures. In section IV we present a wide set of numerical investigations that shed light on the performance of the proposed solutions and the different trade-offs. Finally, in section V the conclusion of the paper and future research are outlined.

II. BACKGROUND

The physical/logical decoupling of user plane (data transmissions) and control signalling paradigm is one of the key architectural directions envisioned for emerging cellular networks that can integrate a large number of heterogeneous small cells [5], [6], [7]. In C/U split architectures macro BSs that provide wide area coverage operate as control (signalling) nodes and are responsible for the overall orchestration and resource management of a large number of small cells within the coverage area and how mobile users are connected to them. Speaking of physical design, the macro BSs include, inter alia, the control plane interface with the Evolved Packet Core (EPC) entities such as the Mobility Management Entity via the 3GPP standardized S1-MME interface. In addition to that, C-plane will also include all LTE signalling and control related functionalities, such as the radio resource control (RRC - establishment, modification, and release of mobile users Radio Resource Control (RRC) layers) network controlled mobility and functionalities related to measurement, configuration and reporting. To ensure full coverage it is also possible for macro BS in addition to control signalling only (C) mode of operation to provide low bit rate services to mobile users (provides functionalities as C+U). On the other hand, small cell nodes would be activated ‘on demand’ and will deliver ultra high bit rates under a small footage area. This term of operation is described as dual connectivity within the 3GPP, since it allows mobile users to maintain simultaneously C-plane and U-plane connectivity from macro and small cell respectively.[2]

III. PROBLEM FORMULATION

In this section, we set the network scenario, define and formulate the related optimization problems for performing load balancing and inter macro cell handover minimization in order to improve the performance of a generic C/U plane split wireless architecture.

[2]For the interested reader further details on small cells enhancements for Release-12 can be found in 3GPP TR 36.842

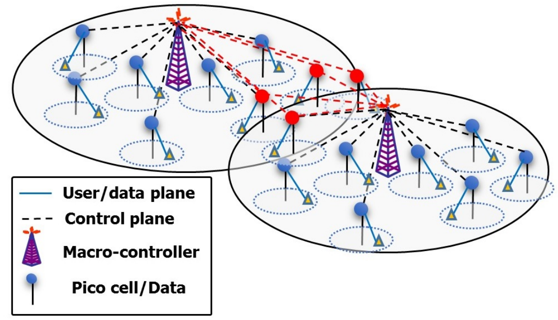


Fig. 1: A generic C/U split wireless architecture with a number of pico cells (each serving 1 user) and red ones are those could be controlled by both macro controllers.

A. Scenario and Problem Formulation

As eluded previously we assume a future high dense network scenario with a cell density of at least ten times higher compared to current levels as expected in 5G networks and in addition to the pico cells we also assume a number of macro-controllers that have overlapping coverage areas. The proposed set of optimization problem relate to the cases where a pico cell can be served by a number of different macro controllers (See Figure 1). This is a pragmatic assumption since such information is readily available from mobile network operators. We assume a set of pico cells and macro controllers P and M respectively. To proceed with a mathematical programming setting we define a binary decision variable x_{ik} as shown in equation (1)

$$x_{ik} = \begin{cases} 1 & \text{if pico cell } i \text{ controlled by macro } k. \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

We also define the average handover rate from pico cell i to neighbor pico cell j by h_{ij}. Furthermore we assume that each macro controller k has a capacity of C_k and each pico cell i based on its current load has a required channel for control signal as g_i, this captures the required L1/L2/L3 control signaling flow including overhead for admission control and synchronization. As mentioned, information about average handover rates is readily available using historical data.

B. Problem Formulation for C-Plane Overhead Reduction

Based on the above network setting we can now define an integer mathematical program for C-plane overhead signalling reduction. The following optimization problem focus on reducing C-plane overhead by assigning pico cells to macro controllers using, previously known, average handover rates between different pico cells. More specifically, a non-linear integer mathematical optimization problem that reduces the overhead on C-plane can be defined. We call this the optimal handover (OPT-HO) problem defined as follows ,

$$[\textbf{Prob 1}] \min \sum_{k\in\mathbf{M}} \sum_{i\in\mathbf{P}} \sum_{\substack{j\in\mathbf{P},\\ j\neq i}} h_{ij}(1 - x_{ik}x_{jk}) \tag{2}$$

$$\text{s.t.} \quad \sum_{i \in P} g_i x_{ik} \leq C_k, \quad \forall k \in \mathbf{M} \tag{2a}$$

$$\sum_{k \in M} x_{ik} = 1, \quad \forall i \in \mathbf{P} \tag{2b}$$

$$x_{ik} \in \{0,1\}, \quad \forall i \in \mathbf{P}, \forall k \in \mathbf{M} \tag{2c}$$

The objective function shows that the overhead costs will be accumulated if handover happens between two pico cells which are controlled by different macro controller. Also note that the objective function is quadratic and hence non-linear, therefore linear programming techniques cannot be applied in this form. Constraint (2a) ensures that the capacity of the macro controller in terms of active supported flows is not violated. Constraint (2b) enforces that each pico cell can only be connected to one macro-controller and constraint (2c) denotes that the decision variables are binary.

However, as already mentioned, the objective function is not linear which deems the above Prob 1 formulation not suitable for utilizing powerful integer linear programming solvers. To re-formulate the above problem into an integer linear problem we introduce the following integer decision variable $Z_{ijk} = x_{ik}x_{jk}$ with $i, j \in P$ and $k \in M$. As can be seen the variable Z_{ijk} takes the value of one only when pico cells i and j are connected to the same macro controller k, otherwise it takes the value of zero. More specifically variable Z_{ijk} can be formally defined as follows,

$$Z_{ijk} = \begin{cases} 1 & \text{if pico cell } i, j \text{ controlled by macro } k. \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

With that in mind, the problem can be re-formulated in an integer linear mathematical program as follows,

$$[\textbf{Prob 1'}] \;\; \min \sum_{k \in \mathbf{M}} \sum_{i \in \mathbf{P}} \sum_{\substack{j \in \mathbf{P}, \\ j \neq i}} h_{ij}(1 - Z_{ijk}) \tag{4}$$

$$\text{s.t.} \quad \sum_{i \in P} g_i x_{ik} \leq C_k, \; \forall k \in \mathbf{M} \tag{4a}$$

$$\sum_{k \in M} x_{ik} = 1, \quad \forall i \in \mathbf{P} \tag{4b}$$

$$Z_{ijk} \geq \; x_{ik} + x_{jk} - 1, \quad \forall i, j \in \mathbf{P}, \forall k \in \mathbf{M} \tag{4c}$$

$$Z_{ijk} \leq x_{ik} \quad \forall i, j \in \mathbf{P}, \forall k \in \mathbf{M} \tag{4d}$$

$$Z_{ijk} \leq x_{jk} \quad \forall i, j \in \mathbf{P}, \forall k \in \mathbf{M} \tag{4e}$$

$$Z_{ijk} \in \{0,1\}, \quad \forall i, j \in \mathbf{P}, \forall k \in \mathbf{M} \tag{4f}$$

$$x_{ik} \in \{0,1\}, \quad \forall i \in \mathbf{P}, \forall k \in \mathbf{M} \tag{4g}$$

C. Load Balancing Problem Formulation

In addition to minimize the overall control overhead we could also provide an association of pico cells to macro controllers so that to achieve load balancing across the various macro controllers. Based on the previous definitions the control related load F_k that has to be handled by macro controller k can be written as follows,

$$F_k = \sum_{i \in \mathbf{P}} g_i x_{ik} \tag{5}$$

Providing load balancing between the macro controllers can be deemed as an important requirement in order to allow for efficient utilization of scarce wireless resources. To this end, a macro controller load balancing problem can be defined. We call this the optimal load balancing (OPT-LB), defined as follows,

$$[\textbf{Prob 2}] \;\; \min \sum_{k \in \mathbf{M}} \left[\sum_{i \in \mathbf{P}} g_i x_{ik} \right]^2 \tag{6}$$

$$\text{s.t.} \quad \sum_{i \in P} g_i x_{ik} \leq C_k, \; \forall k \in \mathbf{M} \tag{6a}$$

$$\sum_{k \in M} x_{ik} = 1, \quad \forall i \in \mathbf{P} \tag{6b}$$

$$x_{ik} \in \{0,1\}, \quad \forall i \in \mathbf{P}, \forall k \in \mathbf{M} \tag{6c}$$

We note that the above is a non-linear integer mathematical programming problem which needs to be linearized in order to utilize integer linear programming solvers. The above defined Prob 2 can be re-formulated as a linear problem if viewed as a max-min optimization problem. In this case, the problem can be re-formulated as follows,

$$[\textbf{Prob 2'}] \;\; \max \;\; t \tag{7}$$

$$\text{s.t.} \quad t \leq \sum_{i \in P} g_i x_{ik}, \; \forall k \in \mathbf{M} \tag{7a}$$

$$\sum_{i \in P} g_i x_{ik} \leq C_k, \; \forall k \in \mathbf{M} \tag{7b}$$

$$\sum_{k \in M} x_{ik} = 1, \quad \forall i \in \mathbf{P} \tag{7c}$$

$$x_{ik} \in \{0,1\}, \quad \forall i \in \mathbf{P}, \forall k \in \mathbf{M} \tag{7d}$$

D. Joint Problem Formulation

The objective functions of Problems 1 and 2 could also be considered jointly by creating a weighted sum objective function to balance between load allocation across the macro controllers and reduction of the C-plane overhead. Such a joint optimization problem can be defined as follows using scalar weights ω_1 and ω_2 to define the contribution in the objective function.

$$[\textbf{Prob 3}] \min\{\omega_1 \sum_{k \in \mathbf{M}} \sum_{i \in \mathbf{P}} \sum_{\substack{j \in \mathbf{P}, \\ j \neq i}} h_{ij}(1 - x_{ik}x_{jk}) - \omega_2 \sum_{k \in \mathbf{M}} \left[\sum_{i \in \mathbf{P}} g_i x_{ik} \right]^2 \} \tag{8}$$

$$\text{s.t.} \quad \sum_{i \in P} g_i x_{ik} \leq C_k, \; \forall k \in \mathbf{M} \tag{8a}$$

$$\sum_{k \in \mathbf{M}} x_{ik} = 1, \quad \forall i \in \mathbf{P} \tag{8b}$$

$$x_{ik} \in \{0, 1\}, \quad \forall i \in \mathbf{P}, \, \forall k \in \mathbf{M} \tag{8c}$$

E. Comparison Scenario: Distance Based Pico Cell Allocation

A nominal mechanism can be assumed, in order to compare with the proposed set of solutions, when a pico cell to macro controller allocation takes place via the Euclidean distance between them or the mean link channel conditions. In this case, pico cells are allocated to a macro controllers which is closest to them compared to proposed scenario that always allocates pico cells pairs with high handover rates to the same macro. Such greedy based allocation can result in significant sub-optimal solution and we provide below a theoretical result on the sub-optimality of such greedy allocation compared to our optimal solution. As shown below, using such a metric the optimality gap is in essence unbounded.

Lemma 1: The gap between the optimal pico cell allocation and that of the distance based allocation can be arbitrarily large.

Proof Consider the topology shown in Figure 2. There are two macro controllers with available capacity $C_i = p$ and a set of $2p$ pico cells with unit requirements of C-plane traffic is shown in pairs where the first set has handover rate equal to h and the second set has as zero. In the optimal allocation (case(a)) the inter-macro controller traffic is zero since there are no handovers between pico cells that are allocated in different macro controllers. In the distance based allocation (case (b)) all pico cells will be connected to the closest macro controller, i.e. the one with distance d1. In that case, the inter-macro controller handover cost would be $\frac{p}{2} \cdot h$ which can be arbitrary large with the available capacity C_i. □

In order to capture the benefits of the proposed set of solutions compared to the baseline distance based small cell association is insightful to evaluate the schemes under different scenarios with variable congestion episodes levels. To this end, we define the congestion level in the network using the following variable , which expresses the ratio between the total C-plane requirements of the small cells in a given geographical area (which depends on the number of small cells as well as the number of mobile users) and the aggregate capacity of the macro controllers.

$$\Omega = \frac{\sum_{i \in \mathbf{P}} g_i}{\sum_{k \in \mathbf{M}} C_k} \leq 1 \tag{9}$$

The equation (9) reveals the congestion level of the problem. If the value of Ω is approaching to 1 then it reveals that network congestion level becomes very high.

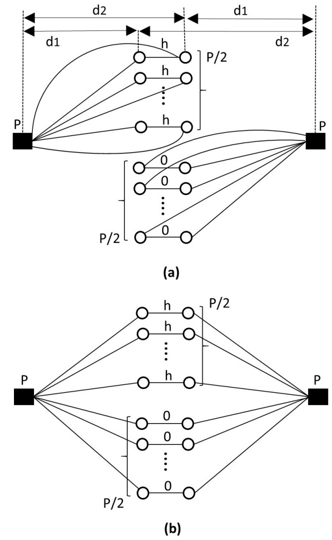


Fig. 2: The scenario depicts $2p$ pico cells that have one unit rate for C-plane requirement and the handover rate between half of the pico cell pairs is h and zero for the rest. The two macro controllers have available capacity $C_k = p$. Case (a) shows optimal allocation with zero inter-macro controller handover overhead, case (b) worst-case allocation of pico cells to macro controllers.

IV. NUMERICAL INVESTIGATIONS

In this section we provide a wide set of numerical investigations to test the performance of the proposed algorithms under various network scenarios and network congestion levels. The system model parameterization and assumptions are built mainly on the proposed C/U split phantom cell concept work that has been presented in [3]. The topology where we applied both optimizations and baseline distance based small cell association is assumed as a 3 overlapped macro cells network and the radius of each macro cell hexagon area is 500 m. The control plane of macro cell is equipped with the control plane interface based on the Evolved Packet Core (EPC) entities. The number of small cells in the investigations ranged in the following discrete values 10, 15 and 20. These small cells are placed randomly in the edge cell overlapped area between different macro cells. In the distance based small cell association, the allocation of small cells is established based on the minimum distance of that small cell with the different macro cells. Therefore, small cells in that case are associated to the nearest macro cell without considering handover rate and/or macro cell congestion levels.

TABLE I: SIMULATION PARAMETERS

Parameters	**Values**
Number of macro cells (M)	3
Number of small cells (P)	10,15,20
Macro cell radius	500 m
small cell radius	50 m
C-plane requirements per UE	0.6 - 0.9 Mbps
Number of UE per small cell	1 - 5
C-plane requirement per small cell (g_i)	0.6 - 4.5 Mbps
Macro cell available capacity for control (C_k)	10 - 35 Mbps
Handover rate (h_{ij})	0 - 1 Kbps
Congestion level (Ω)	0 - 1

In the numerical investigations, macro cells have available capacity C_k and pico cells have the requirement on control data rate g_i as mentioned in Table I (we note that all range of values are uniformly distributed). As estimated from mobility performance part of [3], the per user data rate can reach approximately 0.9 Mbps. Therefore, we assume the range of per user control signaling requirements is uniformly distributed between 0.6-0.9 Mbps. Based on these values and average number of users per small cell we assume that each small cell has a range of control signaling requirements, g_i, distributed between 0.6-4.5 Mbps uniformly in our simulations. The Table I summarizes the main system level parameters that have been used.

A. Inter macro cell handover optimization

The inter macro cell handover rates comparison between different scenarios is shown in figure 3 for the proposed optimization problem and the distance based small cell association heuristic. More specifically, a network scenario with different number of small cells and 3 macro cell controllers is considered and the figure depicts the total handover rates between potential handover small cells in 3 macro cells coverages. The proposed optimization problem provides an average of 37% improvement compared to the distance based heuristic across all network scenarios. This result indicates that the proposed optimization framework provides a significant decrease of the inter macro cell handover rates which translates to signalling overhead and latency on the handover completion.

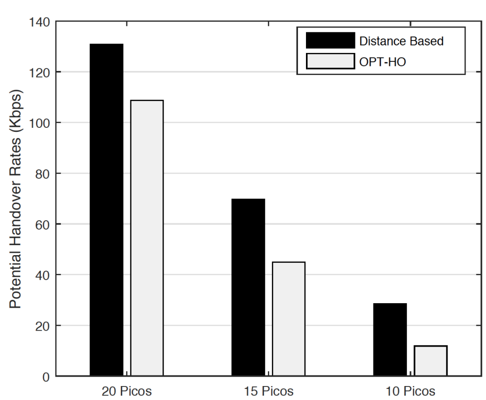
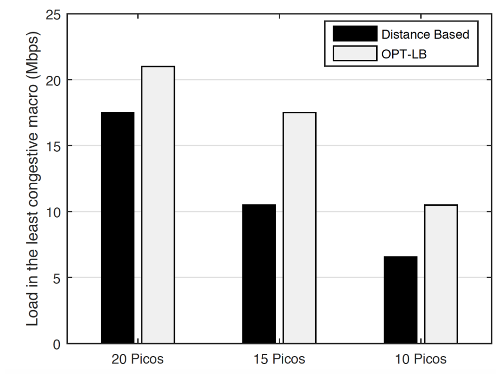
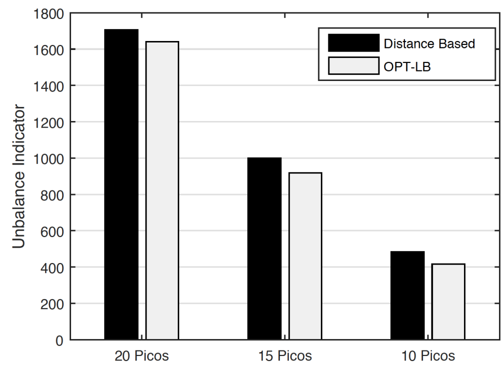


Fig. 3: Performance on inter macro cells handover rates



(a) Load in the least congestive macro (t in Prob 2')



(b) Unbalance level for whole network

Fig. 4: Performance on inter macro cells load balancing

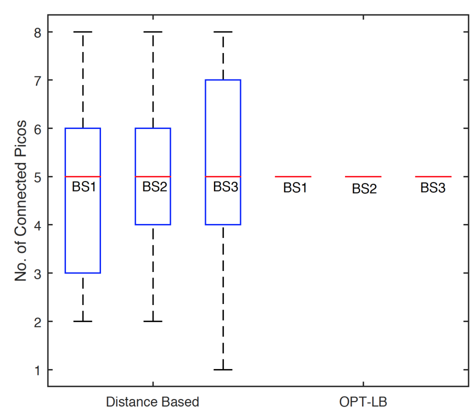


Fig. 5: Picos distribution for 3 macros controlling 15 picos

B. Load balancing across macro cells

The performance evaluation of the proposed load balancing optimization strategy is shown in figure 4. The subfigure (4a) indicates the utilization level on the macro cell which has the minimal conrol traffic for the proposed load balancing scheme and the distance based heuristic for different network scenarios. In addition, subfigure (4b) indicates the unbalance level in the network for different scenarios. As can be observed, the proposed technique provides a performance improvement across all network scenarios in (a) and (b) approximately as 49% and 10% respectively. From these results, it is evident that the proposed technique that strive to distribute load across macro controllers manages successfully to keep the minimal load consumption larger than that of the distance based scheme and always achieve a more balanced distribution. In figure 5 we show the control plane load for each macro cell focusing on the 15 small cells network scenario. The control plane rate requirement for each small cell assume in this evaluation is 3.5 Mbps and the available C-plane capacity for each macro is assumed to be 30 Mbps. As shown in the figure, the proposed optimization algorithm manages to successfully distribute control plane small cell association equally to different macro cells (5 small cells for each macro) compared to the performance achieved by the distance based association which entails a significantly more unbalanced C-plane load distribution (small cells associations for each macro varies unpredictably).

TABLE II: OPTIMIZATION ENHANCEMENT

Enhancement	20 picos	15 picos	10 picos
Handover	16.80%	35.54%	58.42%
Load Balancing	3.28%	10.03%	15.19%

Finally, Table II provides a summary of the numerical investigations and shows the enhancement in handover optimization and load balancing respectively compared to distance based solution. As can be seen, with the increasing of the congestion level, both of optimization algorithms would perform weaker than which in less congestive network.

C. Joint inter macro cell handovers and load balancing optmization

Finally, we discuss the proposed weighted optimization problem that allows for flexible network operation by suitably choosing the weights (ω_i). In a nutshell, the proposed optimization problem 3 aims to allow flexibility to enforce various levels of load balancing and inter macro cell handover rate reduction. Hence, we jointly optimize the C-plane overhead by suitably varying the weights that enforce the contribution of the inter macro cell handovers and load balancing. As shown in Figure 6, we vary the weights ω_1 and ω_2 to consider different levels of contribution for handover optimization and load balancing. As can be observed in the figure, by doing so a Pareto frontier can be calculated as we vary the weights ω_1 and ω_2.

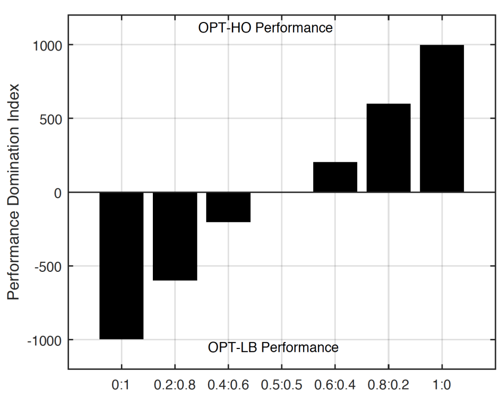


Fig. 6: Optimization Leverage (ω_1:ω_2)

D. Further discussion on the proposed scheme

1) Advantages: The key advantage of the proposed approach is that it allows to consistently provide optimal solutions to both overhead reduction problem and load congestion (balancing) in the control plane traffic. In that respect, provides an upper bound indicator on the performance improvement that can be achieved in the network. We refer to the numerical investigations section of the paper that detail the main benefits of the proposed scheme in terms of performance improvement that can be achieved (load balancing, with a small penalty on the aggregated throughput).

2) Disadvantages, further issues to be considered: However, there are still some disadvantages need to be raised up. First of all is the practical consideration of testing the algorithms. The experimental results are based on extended Monte Carlo simulations using MATLAB but care should be taken to translate those with respect to more realistic network cases in terms for example small cell deployments and actual users handovers that depend on their mobility pattern. Clearly those can vary significantly since they depend very much on the location and user distribution.

The proposed algorithm per se, requires *average handover rates* between adjacent cells to be monitored and being readily available to the algorithm and *cell load factors*. This type of information will need to be communicated from the small cells to the network controller (and being periodically updated). The evaluations was based on assumptions regarding the values of those metrics but to get a more realistic set of results, the algorithms will need to be tested on real world traces. For example, average user handover rates between adjacent cells could be acquired from network operators but it is in general difficult to have access to such data especially for small cells deployments of high density.

Furthermore, the proposed mathematical programming setting is in general not a scalable framework due to the inherent non-polynomial complexity of the problem at hand. Numerical investigations reveal that it is possible to run such a framework for low to medium network size instances but might lead to increased running times for large network instances. Therefore, heuristics and/or greedy solution methodologies need to be defined in order to allow scale free operation for any network instance. One issue that also need to be considered is if there are any conflicts between the proposed algorithms and other network functions in network entities (such as for example admission control, even though this functionality is not being investigated within 5G NORMA). These issues will be more clearly shown and/or clarified via a signalling procedure that will detail how this framework can be cosnidered as a building block of a generic SDMC controller in the network.

V. CONCLUSIONS

Over the next couple of years we expect a high degree of cell densification in cellular networks that will result in an explosion on the utilization of higher spectrum frequencies (mmWave) in order to increase overall spatial capacity. In that setting, efficient, low overhead and complexity network orchestration is emerging as an important tenet of emerging wireless networks. The logical/physical decoupling/split of control and user planes (C/U) is envisioned as a key architectural element to provide the required flexibility in managing small cell networks. To this end, in this paper we detail network optimization algorithms for a generic C/U split architecture with the emphasis being on control plane load balancing and C-plane load reduction by taking explicitly into account the inter macro controller handovers of mobile users as well as congestion levels in different macro cells. In C/U split architectures we therefore aim to ameliorate network congestion episodes where the performance of the network might potentially be limited by the macro-cell control plane capacity rather than the high capacity small cells. Therefore, optimization algorithms for easing the congestion level of the control plane at the macro cells is an important element to ensure a high performance in emerging wireless networks.

ACKNOWLEDGEMENT

This work has been performed in the framework of H2020-ICT-2014-2 project 5G NORMA. The authors would like to acknowledge the contributions of their colleagues, although the views expressed are those of the authors and do not necessarily represent the project. This information reflects the consortiums view, but the consortium is not liable for any use that may be made of any of the information contained therein.

REFERENCES

[1] NGMN Alliance, Next Generation Mobile Networks 5G White Paper V1.0, *NGMN 5G Initiative, February 2015*

[2] 3GPP RWS-120010 WS Docomo, Requirement, candidate Solutions and Technology Roadmap for LTE Rel-12 onward, *3GPP Workshop on Release 12 and on-wards Ljubljana, Slovenia, 11-12 June, 2012*

[3] 5G Radio Access: Requirements, Concepts and Technologies, *Docomo 5G White Paper, July 2014*

[4] Gudipati, A. Perry, A. Li, L. E. and Katti, SoftRAN: software defined radio access network, *In Proc. of ACM SIGCOMM workshop HotSDN 13. ACM, New York, NY, USA, 14-16 Dec, 2015*

[5] Capone A. et al, Rethinking cellular system architecture for breaking current energy efficiency limits, *SustainIT 2012 , pp. 1-5, 4-5 Oct, 2012*

[6] Godor, D3.3: Final Report on Green Network Technologies, *INFSO-ICT-247733 EARTH, Tech. Rep., June 2012*

[7] Ishii, H. Kishiyama, Y. Takahashi, A novel architecture for LTEB :C-plane/U-plane split and Phantom Cell concept, *IEEE Globecom Workshop, 2012 IEEE, pp.624,630, 3-7 Dec, 2012*

[8] Bhushan, N. Junyi Li, Malladi, D. Gilmore, R. Brenner, D. Damnjanovic, A. Sukhavasi, R. Patel, C. Geirhofer, Network densification: the dominant theme for wireless evolution into 5G, *IEEE Communications Magazine, vol.52, no.2, pp.82-89, February 2014*

[9] S. Bhaumik, S. P. Chandrabose, M. K. Jataprolu, G. Kumar, A. Muralidhar, P. Polakos, V. Srinivasan, and T. Woo, Cloudiq: A framework for processing base stations in a data center, *In Proceedings of the 18th Annual International Conference on Mobile Computing and Networking, ACM Mobicom 12, Istanbul, Turkey, 2012*

[10] L. Li, Z. Mao, and J. Rexford, Toward software-defined cellular networks, *In Software Defined Networking (EWSDN), 2012 European Workshop, pp. 7-12, Oct 2012*

[11] M. Bansal, J. Mehlman, S. Katti, and P. Levis, Openradio:a programmable wireless dataplane, *ACM HotSDN 12, pp. 109-114, New York, NY, USA, 2012*

[12] Mahindra, R. Khojastepour, M.A., Honghai Zhang, and Rangarajan, Radio Access Network sharing in cellular networks, *IEEE Network Protocols (ICNP) 2013, pp.1-10, 7-10 Oct, 2013*

[13] Y. Bejerano, S. Han, Cell Breathing Techniques for Load Balancing in Wireless LANs, *IEEE Transactions on Mobile Computing, vol. 8, pp. 735-740, June 2009*

[14] C. Chen, F. Baccelli, L. Roulet, Joint Optimization of radio resources in small and macro cell networks,*in Proceedings IEEE Vehicular Technology Conference, pp. 1-5, May 2011*

[15] J. Han-Shin, J. S. Young, X. Ping, J. Andrews, Heterogeneous Cellular Networks with Flexible Cell Association: A Comprehensive Downlink SINR Analysis, *IEEE Transactions on Wireless Communications, vol.11, no.10, pp.3484-3495, October 2012*